Analysis of Industrial Networks Using Different Wlan Standards

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Abstract

Nowadays, Industrial Ethernet and Wireless Local Area Network (WLAN) have entered strongly into the fields of control and automation. Data acquisition products offer many options regarding the networking of these devices using the above techniques. This paper analyzes the performance of different Industrial WLAN standards (IEEE802.11b, IEEE802.11a and IEEE802.11g) by means of simulation using OPNET package as the network simulation tool. Detailed simulation models of the industrial nodes (sensors & actuators) were built and the effect of different parameters such as WLAN speed, WLAN modes, WLAN topology, traffic intensity…etc. on the system performance were examined. The goal of this study is to determine the maximum limits of the system in order to serve as a real time system suitable for various control and automation tasks.

Keywords

IEEE802.11WLAN; Industrial Ethernet; Delay; Throughput; Real-Time Data

Introduction

For the last few years, wireless communications have been pervading many application areas and are affecting an ever-increasing number of aspects of everyday life.

Compared to its wired peers, wireless LANs have advantages like low cost, fast setup, flexible configuration, user mobility support, etc. During recent years the IEEE 802.11 WLAN standard has been widely deployed as the most preferred wireless access technology [M. Akbar]. The introduction of IEEE 802.11 standard provides basis for interoperability between different products. In addition, the 11 Mbps of IEEE 802.11b and 54 Mbps of IEEE 802.11a offer high speed connections like Ethernet [X. James Dong]. WLAN works without limitation of cabling using either infrared light (IR) or radio frequency (RF) as medium [P. Simacek].

The advantages that wireless technologies offer, lead to various number of possible applications and services, which may be used in industrial fields. Intensive research proceeds at IP based controlling over wireless networks, which will together with Internet relieve remote control [P. Simacek].

At present, wireless communications are used in industrial environments mainly to enable simpler and more cost-effective maintenance and diagnostics functions [G. Cena][G. Cena] [A. Willig]. For instance, low-cost 802.11 access points are sometimes introduced in control networks used at the factory shop-floor to enable diagnostic/ management tools to be temporarily connected that are needed, for example, to reconfigure the control software or change operating parameters[G. Cena].

WLAN was not originally designed for industrial applications and suffers from the same defections. Implementation of new standards such as 802.11a or 802.11g can rapidly enhance WLAN usability in real-time considerations - the new norms introduce faster transmission technologies. A number of technical solutions based on either standard or proprietary wireless communications have already been introduced in automated plants and machines, which take advantage of their features to solve peculiar problems for particular types of applications [P. Simacek].

This paper is investigating performance of various 802.11 WLANs standards with respect to their possible use in industrial environments. We focused on end-to-end delay and throughput of each standard to discover critical values of these parameters and we studied the effect of non real-time data in order to be able to predict the performance of WLAN standards in industrial applications.

This paper is organized as follows: Section II includes a literature review. Section III illustrates the research methodology, section IV includes the description of a current work and simulation scenarios results with a discussion and finally section V provided conclusions and future works.

Literature Review

Throughput and delay are two of the most important metrics to measure the performance of a wireless network. Most published works on the performance of IEEE 802.11 networks have analyzed them both theoretically and experimentally.

P. Simacek et al., the authors described industrial real-time control application using wireless IP-based network. They focused on the ability of using WLAN standards in industrial application.

G. Cena et al., the authors evaluated some performance indices of 802.11 WLANs in view of their possible use in factory environments. They were interested in the delays that packets experience over the wireless channel to reach their intended destination after a transmission request is issued by a station in the network. They evaluated experimentally the statistical distribution of response times. They validated the results by means of a theoretical analysis.

L. Seno et al., the authors have been carried out an analysis of the real-time performance that can be achieved in quality-of-service (QoS)-enabled 802.11 networks. In particular, a detailed analysis of latencies and packet loss ratios for a typical enhanced distributed channel access (EDCA) infrastructure wireless local area network (WLAN) is presented, obtained through numerical simulations.

H. Wu et al., the authors introduced an analytical model based on Markov chain to compute the saturated throughput of WLAN.

Research Methodology

In this paper OPNET is used to build a set of models represents networkable field devices. The simulation procedure adopted in this paper depends on the procedure presented by [Q. I. Ali], which developed an efficient way to simulate field devices. The method divides the simulation in three phases: configuring the OPNET model of a host computer and its network connection, setting the parameters of the virtual data acquisition card (DAQ) then describing the actions and tasks generated from the control software. OPNET does not offer data acquisition as a standardized application. Hence, since the author was concerned to study data acquisition, they modeled it themselves. A modified videoconference application was chosen to model real-time traffic and this application can be configured for different traffic loads in different directions and runs on top of UDP or TCP network stacks. It was thus an excellent simulation vehicle for the purpose of the study. In short, this application layer allows specification of the amount of UDP (or TCP) traffic to be generated, the destination(s) of the packets etc.

The following steps are necessary to develop the data acquisition applications in OPNET environment:

- Defining the size (in Bytes), type (analog or digital) and timing (arrival scheme, i.e., Constant, Exponential etc) of data being transferred from the data acquisition card (DAQ) channels to the computer. For example, Constant arrival every 10 ms of 16 bit analog samples (from a channel) through 32bit (bus width) DAQ yields a packet inter-arrival rate of 100 packet/s with 2Bytes frame size. The above procedure should be repeated for every channel in the DAQ system.
- Configuring the host computer performance involves the choice of Packet Processing Rate according to its CPU frequency [T Skeie]. Packet processing rate reflects the ability of the node to produce and process packets. Packet processing procedures includes the following tasks[Q. I. Ali]:

1. The addition and removal of the headers which belong to layers : four (TCP layer), layer three (IP layer) and layer two (Data link layer).This also includes all necessary calculations on different levels, such as check sum calculation (layers 4 & 3), CRC (layer 2) and all other activities relating to the packet creation and transfer procedures.
2. The action and reaction activities made by different protocols on the different layers in the (TCP/IP) stack. Also, the number, types and speed of network connections should also be determined.

- The last step in building the virtual automation system is to consider the control software actions which are translated into packets generated from each node and directed to other nodes. The important factor here is to give each node the appropriate address (es) to make it visible on the network. Also, it is essential to consider the effect of the control software structure and the delay

required to finish each task. OPNET's custom application feature could be used for this purpose.

Simulation Scenarios

The main issues of industrial applications are transferring time critical and reliability of the communication channel. Through the simulation model, we studied the critical situations for delay and throughput.

We start building the Wi-Fi networking model by creating a projects and work on the model at the OPNET's network layer. A subnet is created to represent the factory wireless network. The work is divided into two categories, first we examined the performance of standard a, b, and g on network with light loads, so we create a network contains two nodes, one act as sensor node and the other as controller-actuator node (with and without access point). Second, we examined the performance of standard a, b, and g on network with medium load, so we create a network contains five sensor nodes and one controller-actuator node (with and without access point). Finally, we examined the performance of standard a, b, and g on network with heavy load, so we create a network contains twenty five sensor nodes and one controller-actuator node (with and without access point).

In each scenario, the network was examined while setting two parameters: packet length (in byte) and packet production rate (in packet/sec). We assumed two states as the boundaries of the system:

A) Short packet length (which assumed to be 100 byte [Q. I. Ali]) with maximum packet production rate.

B) Long packet length (which assumed to be 500 byte [Q. I. Ali]) with maximum packet production rate.

In each case we examined the effect of packet production rate on the throughput of the system by varying packet production rate until reaching saturated throughput (before reaching packets dropping threshold). In all scenarios we assumed that the packet processing speed of sensor nodes is 5000 packet/sec which reflects CPU speed of ≈250 MHz [Q. I. Ali]. Also we assumed the distance between sensor node and controller-actuator node is 100m which is supposed to be reasonable distance in factory floor. For controller-actuator node, the packet processing speed is chosen to be 20000 packet/sec (≈ 2 GHz) in order to serve more requests from the different nodes. In all the following scenarios packet end_to_end delay is expressed using Eq. (1) & Eq. (2):

Packet end_to_end delay= WLAN delay + node delay (1)

Where:

node delay= (1/packet processing speed) + (queuing delay inside node's buffer) (2)

Scenario1:

In this scenario we simulate a network with 2 nodes in an ad hoc mode, one act as sensor node and the other as controller-actuator node.

We simulated all the three standard b, a and g with speed 11, 24 and 54 Mbps. The results of this scenario are arranged as listed in Table 1.

TABLE1 SIMULATION RESULTS FOR SCENARIO1

standard	Packet length (byte)	Packet production rate (packet/sec)	Packet end_to_end Delay (msec)	WLAN Delay (msec)	Throughput (Mbps)
11b	100	1020	34.577	34.326	1.044
11b	500	785	5.748	5.498	3.316
24g	100	3057	7.038	6.788	3.130
24g	500	2173	2.711	2.461	9.178
54g	100	3392	14.294	14.043	3.473
54g	500	2808	2.887	2.637	11.860
24a	100	4501	7.886	7.636	4.609
24a	500	2820	2.134	1.883	11.911
54a	100	5000	0.362	0.112	5.119
54a	500	3988	1.531	1.281	16.845

As noted from the table, the difference between WLAN delay and Packet end_to_end delay is 0.00025. This time represent the processing delay in the nodes (sensor and controller-actuator nodes). According to Eq. (2), the processing delay when the packet production rate is 5000 packet/sec. then the time delay is 0.0002 sec. in the sensor node, and 0.00005 sec. in controller-actuator node, so the total processing delay will be 0.00025. Also it can be seen that increasing packet production rate causes WLAN delay to be increased which in turn increases packet end_to_end delay. Also, it is clear that maximum throughput value depends on the lengths of the packets because of the overhead effect.

Scenario2:

In this scenario an Access Point (AP) is set up as a wireless router between sensor node and controller-actuator node. This scenario simulate all the three standard b, a and g with speed 11, 24 and 54 Mbps. The results of this scenario are arranged as listed in the Table 2.

It is obvious that the maximum throughput was decreased as compared to scenario1 due to the

presence of the access point which causes the transmission to be finished after two hops.

TABLE 2 SIMULATION RESULTS FOR SCENARIO 2

Standard	Packet length (byte)	Packet production rate (packet/sec)	Packet end_to_end Delay (msec)	WLAN Delay (msec)	Throughput (Mbps)
11b	100	575	40.022	39.765	0.589
11b	500	426	17.058	16.802	1.799
24g	100	2240	1.078	0.828	2.294
24g	500	1376	0.854	0.604	5.812
54g	100	2639	3.447	3.196	2.702
54g	500	1975	0.634	0.384	8.342
24a	100	2398	7.092	6.842	2.455
24a	500	1431	1.157	0.907	6.044
54a	100	2866	12.181	11.931	2.935
54a	500	2087	1.704	1.454	8.815

Scenario3:

This scenario simulate ad hoc network with five sensor nodes and one controller-actuator nodes .This scenario simulate all the three standard b, a and g with speed 11, 24 and 54 Mbps. The results of this scenario are arranged in the Table 3 as listed.

TABLE 3 SIMULATION RESULTS FOR SCENARIO 3

Standard	Packet length (byte)	Packet production rate (packet/sec)	Packet end_to_end Delay (msec)	WLAN Delay (msec)	Throughput (Mbps)
11b	100	237	6.711	6.462	1.214
11b	500	172	8.019	7.768	3.633
24g	100	634	0.991	0.741	3.247
24g	500	426	0.868	0.619	8.998
54g	100	724	0.441	0.192	3.707
54g	500	584	0.403	0.154	12.33
24a	100	942	0.460	0.210	4.824
24a	500	544	1.548	1.298	11.49
54a	100	1141	0.745	0.495	5.843
54a	500	812	0.527	0.277	17.150

In this scenario, each node has less chance to transmit its data due to the contention nature of the CSMA/CA protocol with DCF mode which causes to increase end_to_end delay and hence decreasing throughput values.

Scenario 4:

This scenario simulate BSS network with five sensor nodes and, one controller-actuator node and one access point. This scenario simulate all the three standard b, a and g with speed 11, 24 and 54 Mbps. The results of this scenario are arranged in the Table 4 as listed.

From the table, it can be seen that the throughput in all cases have been dropped due to the presence of the access point which caused the transmission to be completed after two hops.

TABLE 4 SIMULATION RESULTS FOR SCENARIO 4.

Standard	Packet length (byte)	Packet production rate (packet/sec)	Packet end_to_end Delay (msec)	WLAN Delay (msec)	Throughput (Mbps)
11b	100	115	13.730	13.476	0.590
11b	500	85	15.783	15.532	1.796
24g	100	445	3.592	3.342	2.279
24g	500	268	1.447	1.200	5.661
54g	100	530	8.596	8.343	2.714
54g	500	390	1.609	1.361	8.237
24a	100	485	16.096	15.842	2.484
24a	500	283	3.576	3.326	5.978
54a	100	584	7.473	7.223	2.991
54a	500	416	3.050	2.800	8.787

Scenario 5:

This scenario simulate ad hoc network with twenty five sensor nodes and one controller-actuator node. This scenario simulate all the three standard b, a and g with speed 11, 24 and 54 Mbps. The results of this scenario are arranged as listed in the Table 5.

TABLE 5 SIMULATION RESULTS FOR SCENARIO 5.

Standard	Packet length (byte)	Packet production rate (packet/sec)	Packet end_to_end Delay (msec)	WLAN Delay (msec)	Throughput (Mbps)
11b	100	44	3.756	3.697	1.132
11b	500	32	5.427	5.448	3.428
24g	100	111	0.702	0.452	2.847
24g	500	74	0.920	0.671	7.819
54g	100	126	0.638	0.388	3.231
54g	500	99	0.709	0.459	10.459
24a	100	173	1.043	0.793	4.434
24a	500	99	1.022	0.778	10.459
54a	100	214	0.707	0.465	5.483
54a	500	151	0.688	0.451	15.950

Scenario 6:

This scenario simulate BSS network with twenty five sensor nodes, one controller-actuator node and one access point. This scenario simulate all the three standard b, a and g with speed 11, 24 and 54 Mbps. The results of this scenario are arranged in the Table 6 as listed.

TABLE 6 SIMULATION RESULTS FOR SCENARIO 6.

Standard	Packet length (byte)	Packet production rate (packet/sec)	Packet end_to_end Delay (msec)	WLAN Delay (msec)	Throughput (Mbps)
11b	100	22	30.108	29.825	0.573
11b	500	16	23.041	22.759	1.701
24g	100	89	11.470	12.631	2.193
24g	500	52	5.247	4.996	5.496
54g	100	105	7.126	6.875	2.693
54g	500	72	2.631	2.382	7.608
24a	100	96	8.709	8.458	2.463
24a	500	56	7.359	7.106	5.919
54a	100	115	6.488	6.253	2.949
54a	500	82	4.451	4.231	8.664

Scenario7:

This scenario simulates ad hoc network with five sensor nodes and one controller-actuator node, when packet length is 100 byte and packet production rate is 237 packet/sec and network speed of 11 Mbps (see Table 3). In this scenario we tested the effect of non real time data on the system by assuming that one sensor node receiving a file of 50Kbyte, 500Kbyte and 1Mbyte size respectively (as reconfiguration instructions from a human machine interface (HMI) wireless server) uses file transfer protocol (FTP).

Fig. 1 and Fig. 2 show clearly the effect of non real-time on the packet end_to_end delay and WLAN delay. It's noted that the presence of non real time data in the system has a negative effect on the system performance which increase the delay value. It can be seen that the packet end_to_end delay and WLAN delay greatly increased when the size of the file sent increased due to the additional load added to the system.

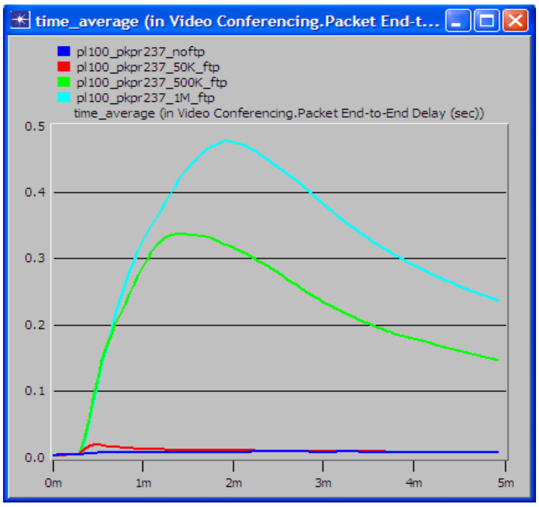

FIG. 1 EFFECT OF FTP ON PACKET END_TO_END DELAY

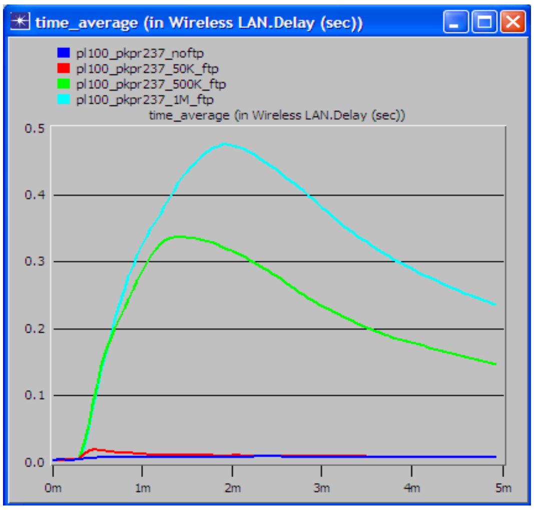

FIG. 2 EFFECT OF FTP ON WLAN DELAY

The extra load added by non real-time data to the system caused the data to be dropped as can be seen from Fig. 3. The figure shows that the data dropped ration is increased when the file size increased.

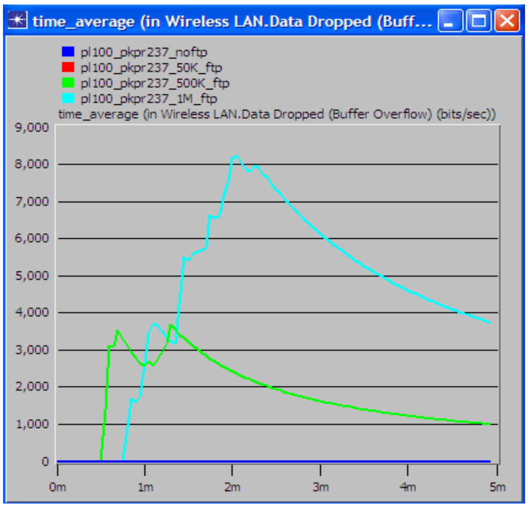

FIG. 3 DATA DROPPED DUE TO THE PRESENCE OF NON REAL-TIME DATA

Conclusion

This paper investigates the real time performance of industrial WLAN. The current performance analysis presents a different detailed look on such networks. It is found that maximum system limits (maximum throughput without dropping) depends on several factors which are:

1. WLAN standard used. IEEE 802.11a gives the best results. However, another research work should be done to check its stability in such environments.
2. Operation mode (Ad hoc or Infrastructure).
3. Data rate of the channel.
4. Number of nodes in the system and their processing capabilities.
5. Message types, length and their production scheme and rate.
6. Presence on non real time data on the network.

The effect of non real-time data has been also studied. The results showed that, this type of data greatly affects the performance of real-time system through increasing the delay time and dropping ratio.

The current work could be extended to include the followings:

1. Effect of WLAN security methods on the system performance.

2. A field test must be achieved to check the stability of different IEEE 802.11 standard in the industrial environments.
3. A further analysis must be achieved to reduce the effect of non real-time and enhance the performance of the system.

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